TM-1448

ACCELERATION GRADIENT FOR THE 400-MEV LINAC UPGRADE

Robert J. Noble

April 10, 1987

ABSTRACT

The issue of the acceleration gradient for the 400-MeV Linac Upgrade has been examined. An average axial field of at least 7.5 MV/m is required to accelerate an H^- beam from 116 MeV to 400 MeV in the existing Linac enclosure. The present Linac Upgrade design assumes an operating frequency of 805 MHz to allow acceptable longitudinal bunch matching from the 200 MHz Alvarez linac and ensure commercial availability of the necessary high power rf sources. At 805 MHz the maximum average axial field above which conditioning times and x-ray emission become excessive is estimated to be 8 MV/m, which is consistent with the field required to achieve the Linac Upgrade energy.

INTRODUCTION

The Linac portion of the Tevatron Upgrade program will increase the energy of the existing 200-MeV linac to 400 MeV in order to reduce beam emittance degradation in the Booster. By increasing the Linac energy to 400 MeV, the phase space density limitation (defined by the ratio of the number of particles to the beam emittance) a few milliseconds after injection into the Booster can be increased by about a factor of 1.75. Although a higher Linac energy would increase this limitation even more, the choice of 400 MeV is dictated by the fact that at most a 400-MeV H^- beam can be transferred without stripping through the existing twisted passage to the Booster. The present constraint that no Linac Upgrade construction disrupt the accelerator operation precludes any modification of the transfer passage to accommodate a beam with energy greater than 400 MeV.

The Fermilab 200-MeV Alvarez drift-tube linac was designed in the late 1960's. At the time it was known that other accelerating structures were more efficient (i.e. higher shunt impedance) above 100 Mev, but for the sake of replication of components and simplicity, it was decided to continue the drift-tube structure to 200 MeV. The Linac Upgrade project provides for the replacement of the last four Alvarez tanks with a more efficient, higher accelerating gradient structure. The last four tanks now accelerate the beam from 116 MeV to 200 MeV in approximately 60 meters, and the new structure would have to accelerate the beam to 400 MeV in the same length. Consequently the new structure will have to operate at a gradient of at least three times that of the Alvarez structure.

SURFACE FIELD BREAKDOWN

The average axial electric field E_0 of a structure is defined by:

$$E_0 = \int_{cell} E_z^0(z)\,dz/L_{cell}, \tag{1}$$

where L_{cell} is the acceleration cell length, and $E_z^0(z)$ is the amplitude of the longitudinal electric field. The field is essentially zero inside the drift tube. The gradient E_0 is related to the energy gain per cell length $\Delta W/L_{cell}$ by:

$$\Delta W/L_{cell} = eE_0T\cos\phi_s, \tag{2}$$

where ϕ_s is the synchronous phase angle, and the transit time factor

$$T = \int_{cell} E_z^0(z)\cos(2\pi z/L_{cell})\,dz/\int_{cell} E_z^0(z)\,dz \tag{3}$$

takes into account the variation of the standing wave field as the particle crosses the cell. The present Alvarez structure operating at 200 MHz has $E_0 \simeq 2.5$ MV/m so a new structure which would accelerate the beam to 400 MeV would need to have an axial gradient of at least 7.5 MV/m.

An average axial field of 7.5 MV/m is a higher field than used in any existing proton or H^- linac. However to put this value in perspective requires a criterion for judging high fields. The maximum gradient that a structure can operate at is determined by surface field breakdown for frequencies below which melting from surface heating occurs ($\simeq$ 300 GHz if the rf pulse length equals the structure filling time).[1] The surface field E_s is related to the average axial field E_0 by a proportionality factor dependent on the structure,

$$E_s = \alpha_s E_0, \tag{4}$$

where α_s typically varies from about 2 for a disc-loaded waveguide (e.g. SLAC) to 6 for a standing wave linac (e.g. FNAL Alvarez). The maximum surface field at which catastrophic breakdown invariably occurs in clean, baked vacuum systems after conditioning has been found to approximately obey the relation[2]

$$E_b(\mathrm{MV/m}) \simeq 180[f(\mathrm{GHz})]^{\frac{1}{2}} \quad , \tag{5}$$

where f is the frequency. Historically surface breakdown fields had been determined by the Kilpatrick criterion[3]

$$E_K(\mathrm{MV/m}) \simeq 33[f(\mathrm{GHz})]^{\frac{1}{2}} \quad , \tag{6}$$

established at a time when untrapped oil diffusion vacuum pumps were used.

MAXIMUM OPERATING FIELD

Although catastrophic breakdown can be avoided just below the limit of Eq. (5), long conditioning times and high x-ray production from field emitted electron bremsstrahlung result as the limit is approached. Excessive x-ray emission both damages beamline organics (e.g. seals, insulation) resulting in significant downtime and drains expensive rf power. For these reasons it is prudent to take the maximum operating surface field $E_{s(max)}$ in the range (.25-.5) E_b.[4] Early 200 MHz cavity studies showed that excessive x-ray emission (400 R/h) occurred for $E_s \simeq$ .5 E_b(200 MHz) $\simeq$ 40 MV/m, while for $E_s \simeq .3\ E_b \simeq$ 24 MV/m x-ray emission was reduced to an acceptable level (4 R/h).[5] The present FNAL 200 MHz linac operates with a surface field of only 15 MV/m ($\simeq E_K$(200 MHz)). Based on these considerations, it would appear reasonable to assume a maximum operating surface field

$$E_{s(max)} \simeq .3\ E_b \ . \tag{7}$$

To obtain $E_0 \simeq 7.5$ MV/m required for the 400-MeV Linac Upgrade implies a surface field $E_s \simeq 6\ E_0 \simeq 45$ MV/m which is nearly twice the limit imposed by Eq.(7) at 200 MHz. Consequently a higher frequency accelerating structure is needed to provide the surface fields for the Linac Upgrade.

The choice of frequency is influenced by several factors. High power rf klystrons are commercially available for frequencies at or above 800 MHz. In going from a lower to higher frequency structure, care must be taken in matching the longitudinal phase space of the beam to the new structure. The rf accelerating bucket is shorter in a higher frequency structure, and the beam must fit into this bucket without emittance growth or beam loss. A frequency of 805 MHz (4th harmonic of the present linac) does allow acceptable longitudinal matching from the Alvarez linac and is used as the operating frequency in the Linac Upgrade design. At 805 MHz, $E_{s(max)} \simeq 48$ MV/m from Eq. (7) corresponding to a maximum average axial field of $E_{0(max)} \simeq E_{s(max)}/6 \simeq 8$ MV/m. At this frequency then, the choice of $E_0 \simeq 7.5$ MV/m to achieve the Linac Upgrade goal is consistent with the maximum operating field allowed by conditioning times and x-ray emission. Since accelerating structures differ greatly in detail, it will be crucial to perform actual power testing of any new structure for the Linac Upgrade to establish the difficulty of achieving reliable operation in the range 7-8 MV/m.

REFERENCES

1. P.B. Wilson, in "Laser Acceleration of Particles" (Malibu, CA 1985), A.I.P. Conf. Proc. No. 130, C. Joshi and T. Katsouleas, eds. (A.I.P., New York, 1985).

2. E. Tanabe, J.W. Wang, and G.A. Loew, in Proc. of the 1986 Linear Accel. Conf., Stanford, CA, p. 458.

3. W.D. Kilpatrick, Rev. Sci. Inst. 28, 824(1957).

4. G.A. Loew, private communication.

5. "Preliminary Sparking and X-Ray Phenomena in a 200 Mc Linac Cavity", Midwestern Univ. Research Assoc.(Wisconsin), TN-535 (March 17, 1965).